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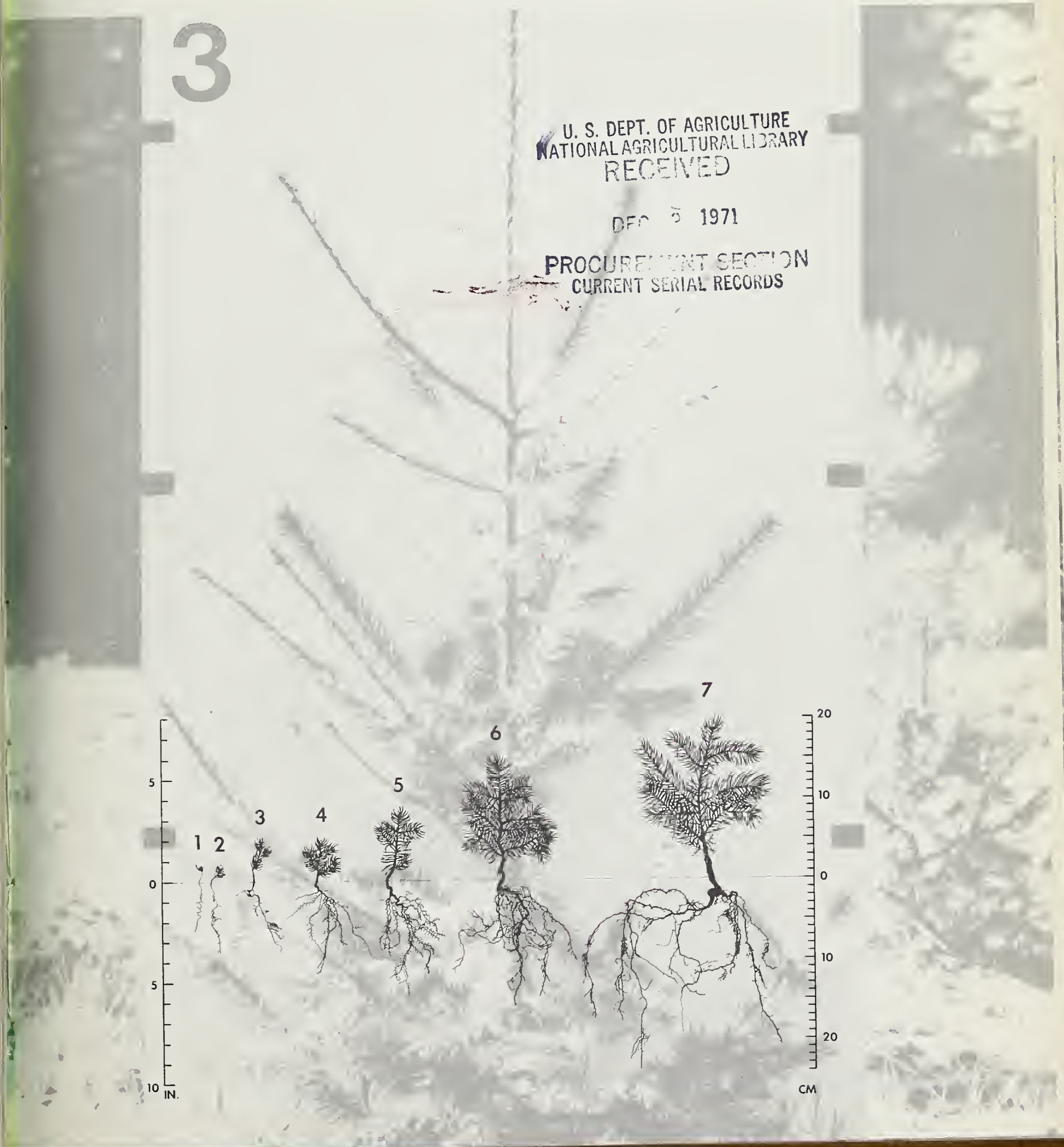
MIXED CONIFER SEEDLING GROWTH in Eastern Arizona

by John R. Jones



Abstract

Seedling height growth of several species was reconstructed on five case-study areas. Root development of natural seedlings is also shown at different ages. In a small opening receiving no direct sunlight, height growth was very slow. Engelmann spruce and corkbark fir seemed healthy after six growing seasons; white fir and Douglas-fir did not. In an abandoned roadway receiving direct sunlight briefly at midday, growth was moderately faster and all four species seemed healthy. Seedlings grew much faster in a clearcutting, where ponderosa and southwestern white pine also were measured. Growth of Engelmann spruce and corkbark fir understory seedlings released by partial cutting increased markedly. Douglas-fir growth did not. On a burn, growth of Engelmann spruce seemed reduced by intense overstocking. Implications for forest management are discussed.

KEY WORDS: *Pseudotsuga menziesii*, *Picea engelmannii*, *Abies lasiocarpa*, *Abies concolor*, *Pinus ponderosa*, *Pinus strobiformis*, seedlings, roots, overstocking effect.

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John R. Jones

In the Southwest, mixed conifer forests occupy many sites that are too moist for a ponderosa pine [2] climax. They usually include Rocky Mountain Douglas-fir, which normally shares the crown canopy with one or more of the following: ponderosa pine, white fir, southwestern white pine, Engelmann spruce, blue spruce, corkbark fir, and quaking aspen. Any of the conifers may predominate, but areas dominated by blue spruce or white pine normally amount to little more than groves within the forest.

We have had few data until now on seedling growth rates in the southwestern mixed conifers. This study consists of case histories of seedling growth rates on five areas with different sets of conditions, including several levels of stand opening, in mixed conifer forests in Arizona's White Mountains. It also provides a first look at seedling root systems.

The Study Sites

The main study area is in east-central Arizona at approximately 33° 37' north latitude, 109° 19' west longitude, about 9,100 feet above sea level.

On the sites studied, snow usually covers forested ground from sometime in November or December until April or May. On steep southerly slopes, however, patches of ground are likely to be bare at times during the winter, particularly in the open. In many years remnant snowbanks can be found in June.

May and June constitute the "dry season." Little rain falls during those months, but initially wet soils combined with cool temperatures moderate the lack of rain. July and August have considerable cloudiness, frequent showers, and in most years abundant rain.

Air temperatures seldom reach 80° F. in the study areas. Frosts are common on June nights where cold air collects, but limited data suggest that frost is uncommon in June where there is free air drainage at night, as on the study sites.

[2]Common and scientific names of plants mentioned are listed on page 19.

While rugged terrain is common in the White Mountains, there is considerable upland with gentle or moderate slopes. The study sites are on gentle slopes on a broad divide between the Blue and Black River drainages. The soils are of basalt origin.

Height growth was studied on four primary sites very near one another. One was a clearcut area (fig. 1) with a very gravelly loam soil. In its center was a shallow gravel pit. It had numerous postlogging seedlings of several species. A second site was a small opening in the forest (fig. 2), typical in most respects of those formed by the death or removal of a single large tree. The soil was a gravelly loam. A small pile of logging debris was burned there, and seedlings were unusually abundant, presumably because dragging and burning disturbed or destroyed the duff layer. The seedlings received abundant skylight, but no direct sunlight even at the summer solstice except in the form of transient sun flecks. The third site was intermediate in the amount of light it received. It was an abandoned north-south

Figure 1.--Clearcut area with gravel pit in the center.

Figure 2.--Small opening in forest; the photograph shows its full width.

roadway with about a 20° opening overhead (fig. 3). Seedlings received about 1.5 hours of direct sunlight at midday. The light conditions seemed roughly comparable to those of seedlings in forest stands that have received moderate partial cutting.

On the third site, the seedlings were taken from the roadside where the ground had not been compacted by traffic. There were also many seedlings on the road itself; frost action probably had loosened its compacted surface in the 12 years since abandonment. The roadside, too, had been graveled, so the ground from which the sample came was not natural. Seedlings were very abundant on the graveled roadbed, and very scarce off the gravel.

The fourth principal study site (fig. 4) had been virgin forest until it was cut selectively in 1957. Cutting was moderate, but subsequent blowdown reduced stocking irregularly to a level characteristic of stands that have had a heavy partial cutting. Most such post-logging blowdown ordinarily follows within a few years after harvest—especially the year immediately following—and that probably is

Figure 3.--Abandoned north-south roadway.

Figure 4.--Area in which seedlings had been released by partial cutting in 1957, and further released by subsequent blowdown.

what happened here. On this fourth site there had been numerous irregularly distributed seedlings before harvest. Their growth in the 13 seasons since then provides a case history of seedling response to overstory removals, and the area will be referred to as the release area.

Other data were collected in the Engelmann spruce-corkbark fir type 25 miles north-northeast of the sites described above, at 10,600 feet elevation, on a part of the Escudilla Mountain Burn where an extremely dense seedling stand became established near unburned timber (fig. 5).

These sites were chosen because they had sufficient suitable material growing in rather uniform conditions. Also, except for the Escudilla Mountain site, they were very near one another, and appeared similar except for the amount of gravel in the topsoil and the effects of different degrees of stand opening.

Around all but the release site and the Escudilla Mountain site, Douglas-fir is the predominant canopy species, but corkbark fir and Engelmann spruce are also abundant in the canopy, and white fir, white pine, and ponderosa pine are present. There are no blue spruce on or near any of the sites. On the release site, Engelmann spruce and corkbark fir both are more abundant than Douglas-fir in the overstory; around the Escudilla Mountain site they were the only species, Engelmann spruce predominating.

Figure 5.--Part of the Escudilla Mountain Burn, at 10,600 feet, with abundant Engelmann spruce and some corkbark fir.

The seedling root systems studied were dug up on nearby areas that were less gravelly than the clearcutting and the old roadway. These sites had few seedlings below age 5. Except for first-year seedlings, the exhumed seedlings of each species were dug up in a single small site. For the most part the different species were not found in suitable abundance in the same place, so that, for example, Engelmann spruce were dug up in a different place from white fir. White fir and white pine were dug up together in a rather open virgin stand. The corkbark fir seedlings were growing together with Douglas-fir seedlings in a partially cut stand. The Engelmann spruce seedlings were dug up at the forest's edge along a shady roadside with a ditch separating them from the pavement.

Only in the case of Engelmann spruce were first-year seedlings found where the older seedlings were dug up. The first-year corkbark fir seedlings were growing with the Engelmann spruce. First-year seedlings of the other species were dug up along the timber margin in a fresh clearcutting.

Material

Not all species were available on each study area. For example, ponderosa pine was found only in the clearcutting.

Only healthy looking trees were used. The basic criterion was that the seedling or sapling looked as if it had a good chance of someday being part of the crown canopy. In addition, a tree was rejected if its height growth had been set back—for example, if the terminal had been bitten off at some time.

Root development was studied only on seedlings that could be removed from the wet loams with trowel, shovel, digging bar, and screwdriver without losing any rootlets. These relatively small seedlings are most susceptible to drought, frost heaving, and competition from grass and other herbs.

Methods

To reconstruct past height growth, nodes were counted back to the ground and total age checked by a basal ring count. In questionable cases, stems were dissected and rings counted. Where a question persisted, total age was based on a basal ring count, and the obscured height of the lowest node or nodes was left out of the tabulations. For those trees, height-age coordinates began with the second- or third-year heights.

Measurements were from the existing surface level. The height given for the end of the first growing season is not necessarily the sum of the hypocotyl and plumule lengths. It also reflects the depth of the seed within the forest floor at the time of germination, subsequent partial frost heaving, erosion, and the deposition of sediment and litter.

Top Growth

The Small Opening

No ponderosa pine seedlings were found in the small opening, although there were mature ponderosa pine nearby. None of the few white pine seedlings looked like candidates for the crown canopy, and consequently none were measured.

There were about two dozen Douglas-fir seedlings present (Douglas-fir predominated in the canopy) but only five were measured. The others seemed to be declining; growth was diminishing or leaders were dead, and usually the foliage looked unhealthy.

Only eight white firs were measured. A number of others were found but seemed to be declining.

Corkbark fir seedlings were no more numerous than Douglas-fir, but few were rejected. Eighteen were measured.

Although corkbark fir was somewhat more abundant in the canopy, and Douglas-fir much more abundant, Engelmann spruce seedlings were much more numerous. None of the spruce looked at were declining, and 24 were sampled along a transect.

The species samples are therefore not strictly comparable. The sample of Engelmann spruce represents all of the Engelmann spruce seedlings on the study site. The Douglas-fir seedlings, however, and those of white fir, were the most vigorous seedlings of those species.

Almost all seedlings were five, six, or seven growing seasons old; a large majority were six.

At the end of the first growing season, the germination year, Engelmann spruce seedlings averaged smallest, about 0.75 inch tall, and white fir were the largest, over 1.25 inches tall. After six growing seasons, however, the sample seedlings of all species averaged about the same height—approximately 5 inches.

The height growth curves of Engelmann spruce and corkbark fir are shown in figure 6. Variations of growth rates within the two species were not large. The standard deviations of their heights at age 6 were almost identical: 1.32 inches for Engelmann spruce and 1.31 inches for corkbark fir.

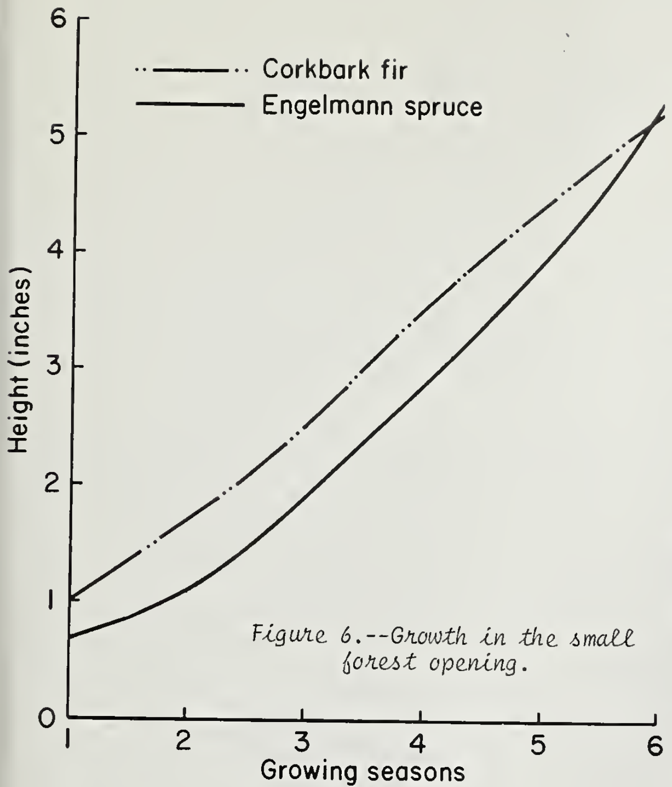


Figure 6.--Growth in the small forest opening.

The Clearcutting

Only trees growing outside the gravel pit were measured, although many growing in the pit were large and healthy. Figure 7 shows the average height growth curves for all species. Table 1 gives additional statistics.

Although ponderosa pine averaged tallest, the tallest individuals were Douglas-fir. One sixth-year Douglas-fir was 42 inches tall, with 1970 leader growth of 23.5 inches. During the sixth growing season it more than doubled its previous height. The tallest tree measured was a seventh-year Douglas-fir (fig. 8) more than 4 feet tall.

Old Roadway

Almost all the seedlings growing beside the old road were Douglas-fir, Engelmann spruce, and corkbark fir, in that order, and they were the only species measured.

As shown in figure 9, the average height after six growing seasons was about 7.5 inches for each species, with standard deviations between 1.5 and 2 inches. They had grown about 50 percent taller than in the small forest opening in the same amount of time, and unlike those in the small opening, the growth rates in the old roadway were clearly accelerating. The several white fir present also seemed healthy.

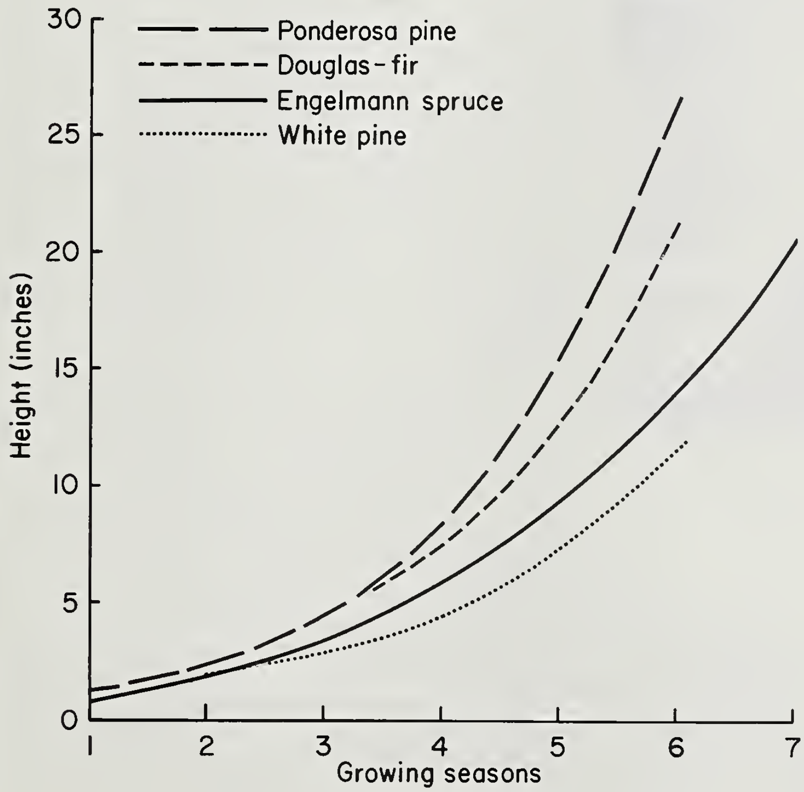


Figure 7.--Growth rates in the clearcutting.

Table 1.--Average heights and standard deviations of seedlings measured in the clearcutting

Species	No. of seedlings	Age by growing seasons	Average height	Standard deviation
			- - - Inches	- - -
Ponderosa pine	24	6	26.7	8.2
Douglas-fir	25	6	21.3	9.7
Engelmann spruce	23	7	20.5	4.9
White pine	9	6	13.3	5.4

Figure 8.--Tallest tree in the clearcutting--a seventh-year Douglas-fir.

Escudilla Mountain

The Engelmann spruce on Escudilla Mountain, like those in the clearcutting, came up in the open, but they were older—mostly 16 and 17. Crown classes had become differentiated and only dominants were measured.

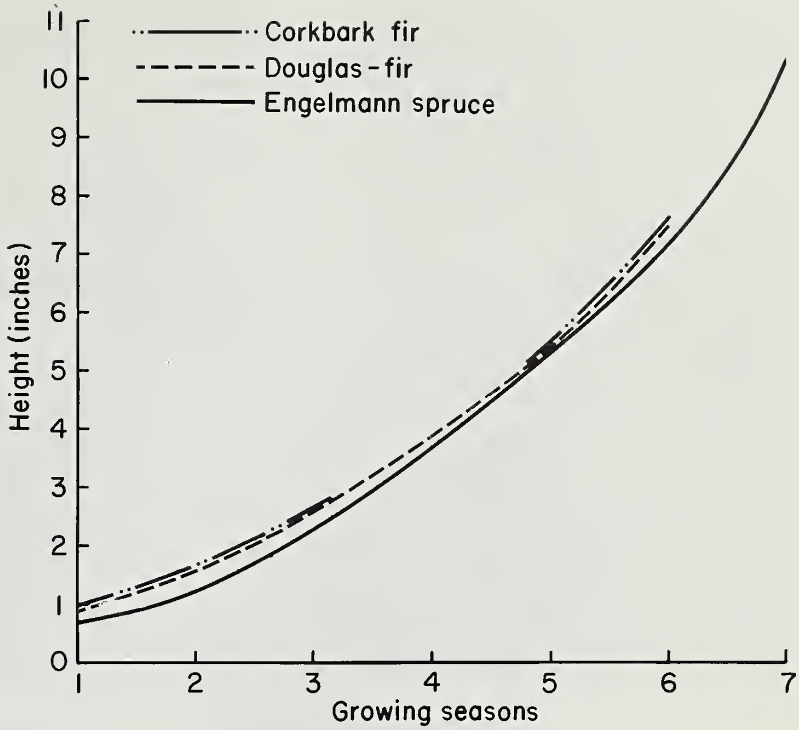
Figure 10 shows a very different growth pattern than might have been expected after examining growth on the clearcutting. After 16 growing seasons the average height of the 12 measured dominants was only 54 inches, with a standard deviation of 18 inches. The growth rate of the average tree has remained essentially uniform since the fourth year, at about 4 inches a year. In the clearcutting, and even in the roadway, height growth had been increasing instead of uniform.

The only apparent explanation for that slow growth is competition—the stand is intensely overstocked (fig. 11). Foiles (1961) found that the number of Engelmann spruce seedlings in a seed spot did not influence the height growth of the dominant one among them; 17-year-old saplings alone in a spot were not taller than the dominants in spots with as many as 16 saplings. But Foile's seedspots were 6 feet apart, while on the Escudilla Mountain site heavy stocking is almost continuous, a considerably different competitive situation. The stocking in figure 11 looks extremely heavy, and it actually is even heavier than it looks. Many seedlings, alive and dead, are not visible in the picture because they have been overtopped.

Also, on this site the dominants that are less crowded than most are notably taller than the average (fig. 10). Those most severely crowded, as around the spade in figure 11, are notably shorter. Since the dominants receive abundant sunlight, the effective competition is presumably for moisture, nutrients, or both.

The internodes for certain years were rather consistently longer or shorter than average. (This is not reflected in the graph because different trees reached a given age in different years.) Because the vegetative season is very cool and moist at 10,600 feet, it seemed reason-

Figure 9.--
Growth in the abandoned roadway.



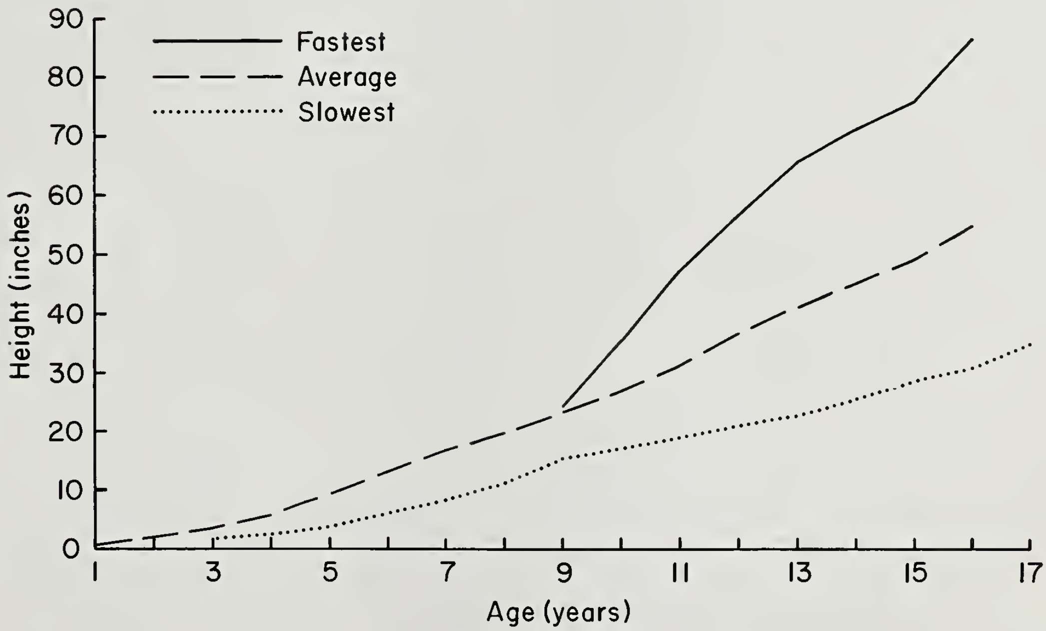


Figure 10.--Growth of Engelmann spruce on Escudilla Mountain.

Figure 11.--Overstocking on Escudilla Mountain.

able to expect that the positive growth anomalies resulted from warmer-than-average temperatures during some critical period, and negative growth anomalies from cooler-than-average temperatures.

The 3 years with largest height growth anomalies were not related to temperatures for the period of shoot elongation, nor for the period of bud formation in the preceding summer, nor for any other period of the preceding vegetative season. Data on precipitation or on duration of snow cover in spring were not available, and the growth anomalies remain unexplained. Temperatures may be a contributing factor, but if they are, it is not a simple relationship.

In the release area, only trees were measured whose nodes could be identified satisfactorily for all years back to 1957, the last growing season before release. Virtually all the regeneration was Engelmann spruce and corkbark fir. Leaders of almost all of the young corkbark fir had been browsed off at least once, and no white fir and only one acceptable Douglas-fir were found. Therefore, only Engelmann spruce were studied. Two unbrowsed corkbark fir were measured; their growth had been about like that of the spruce.

The trees measured all were equivalent, within the regeneration layer, to dominants. Only trees that had still been seedlings in 1956 were wanted in the sample. This caused no problems; trees that had been as much as 2 feet tall in 1957 were too tall to measure in 1970 with the equipment used. The average sample tree of the 14 measured had been 7 inches tall at the end of 1957 and grew to 91.6 inches by the end of 1970 (fig. 12). Growth rates have been increasing ever since release, and in 1970 the leaders averaged about 14.5 inches. That 1970 average conceals considerable variation, however; the standard deviation was 5.8 inches and the longest leader measured was 27 inches. Although all trees measured were free overhead, there was considerable variation among them in light received, and trees receiving more light clearly tended to be taller.

The growth data given above are probably conservative, because the sample is probably biased. There almost certainly are other sapling-dominants on the site that had been no taller in 1957 than the sample trees, but which subsequently had grown too tall to be measured with the equipment used.

Roots

Little is known about the form, behavior, or ecology of seedling root systems in southwestern mixed conifers. Those described here are a limited sample, and only the first-year seedlings came from a clearcutting. Many seedlings were dug previously at other White Mountain locations, mostly for transplanting,

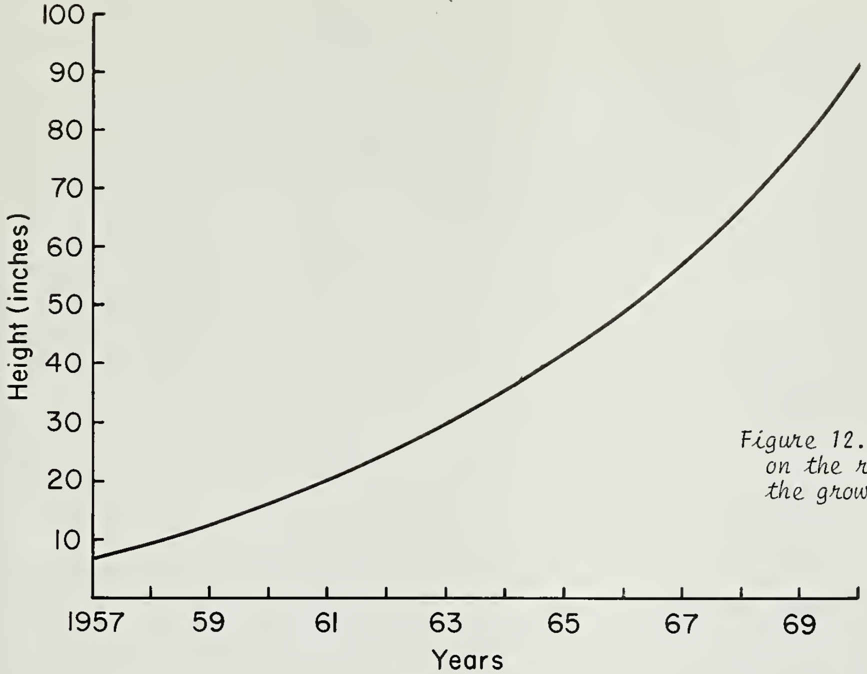


Figure 12.--Growth of Engelmann spruce on the release area. (Released between the growing seasons of 1957 and 1958.)

and the impressions gained from them tend to support, rather than qualify, findings in the study sample.

Different species germinate at different seasons, and their root penetration varies considerably at the end of their first growing season (table 2). Those that germinate in the spring—white fir, corkbark fir, and some white pine—face a spring dry season very soon after germinating. Those that germinate in summer, after the rains begin, do not face a spring drought until the following year.

Figures 13-24, amply illustrate the findings of the root study. In figures showing an age sequence, the seedlings were chosen to represent median size and form within the sample. Other figures illustrate extremes. There were far fewer white pine and ponderosa pine seedlings than for other species.

Table 2.--Germination, and vertical root penetration during the first growing season

Species	Germination season	Average penetration
		Inches
White fir	Spring, on melt moisture	7.3
White pine	Spring, and again in summer after rains begin	7.3
Ponderosa pine	Summer, after rains begin	(1)
Corkbark fir	Spring, on melt moisture	3.4
Douglas-fir	Summer, after rains begin	3.1
Engelmann spruce	Summer, after rains begin	2.7

[1]Only two in sample.

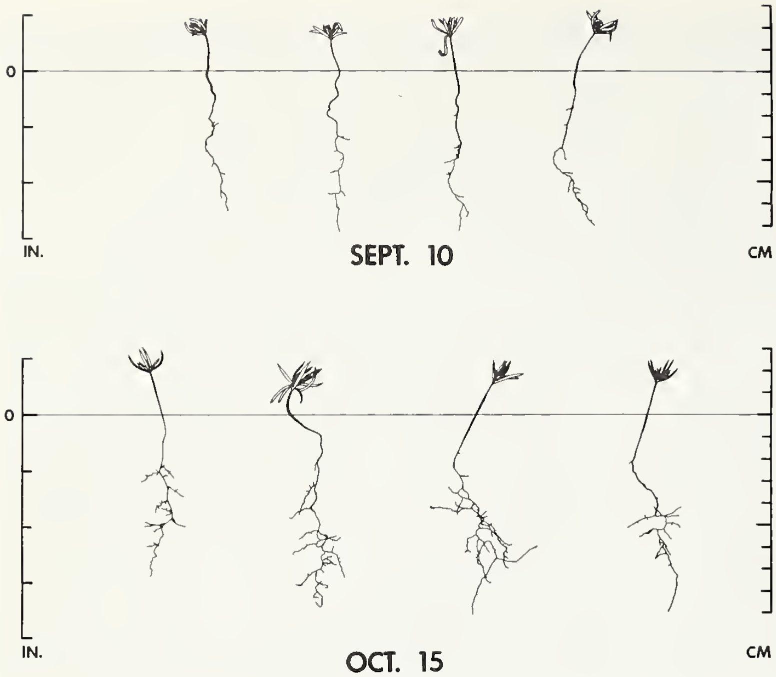


Figure 13.--Uniformity of corkbark fir after one growing season, and comparison of seedlings dug up on two dates. From a shaded roadside site.

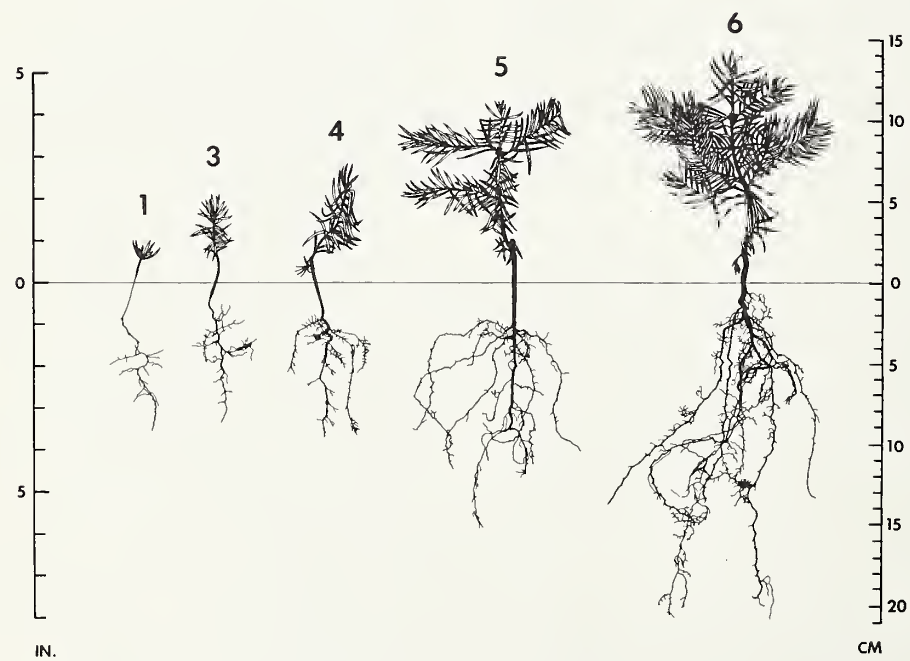


Figure 14.--Representative corkbark firs after one to six growing seasons (no second-year seedling). All but no. 1 from a single forested site.

Figure 15.--Variation in corkbark fir seedling rooting habit on a single forested site.

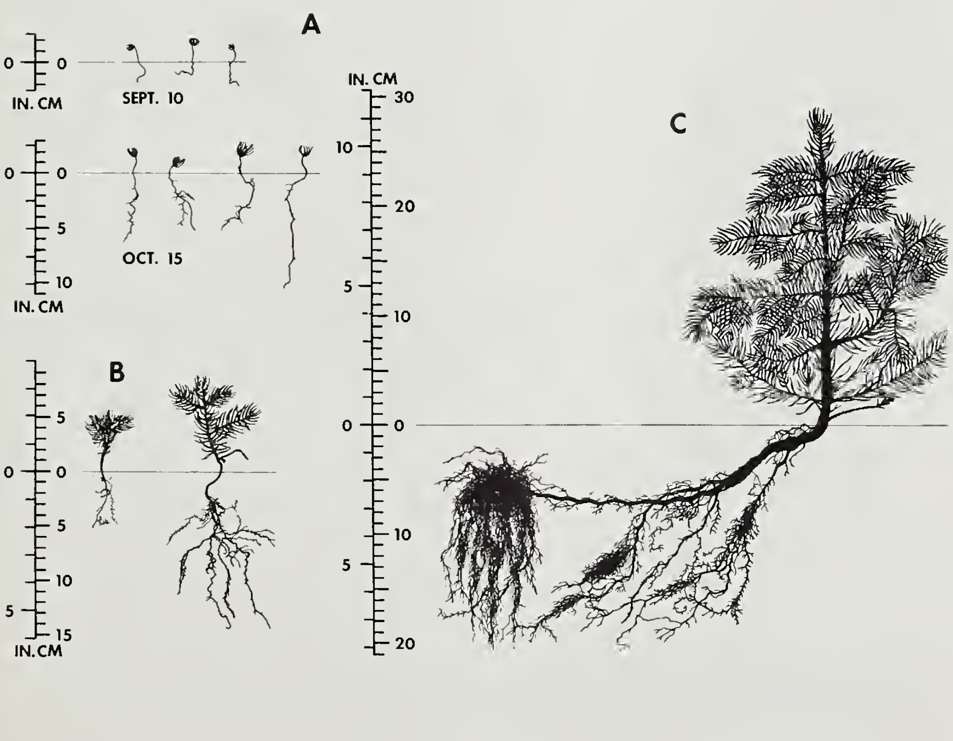


Figure 16.--Engelmann spruce from a shady roadside site.
A. Variation after one growing season and comparison of seedlings dug up on two dates.
B. Largest and smallest fourth-year seedlings.
C. Seventh-year seedling with an unusual root system.

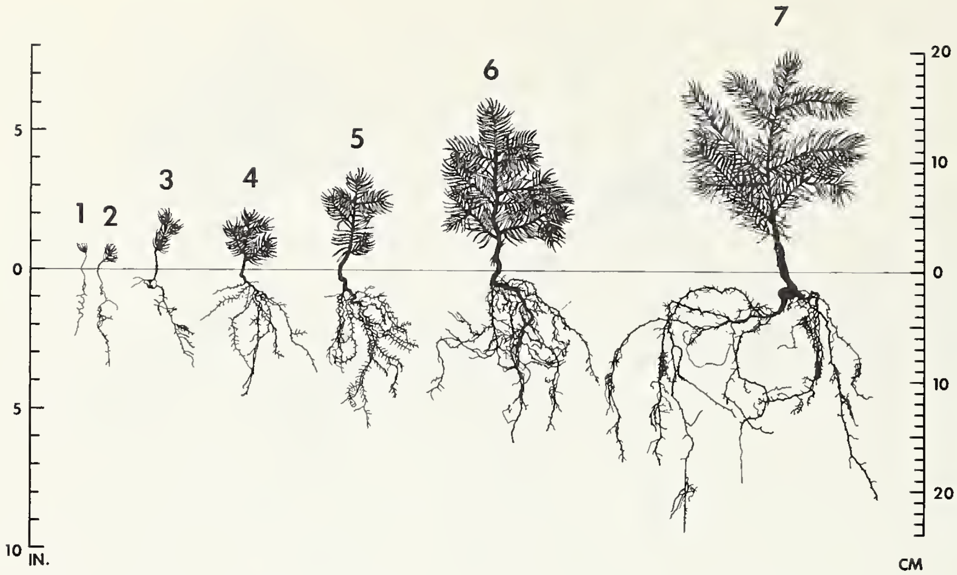


Figure 17.--Representative Engelmann spruce seedlings after one to seven growing seasons on a shady roadside site.

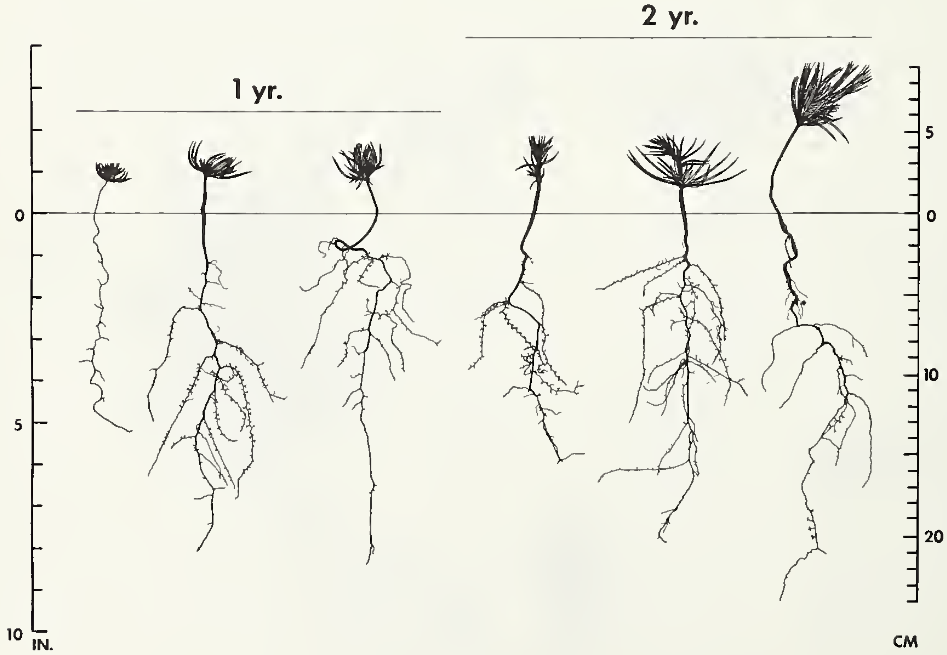


Figure 18.--White pines after one growing season in a clearcutting and after two growing seasons in the forest.

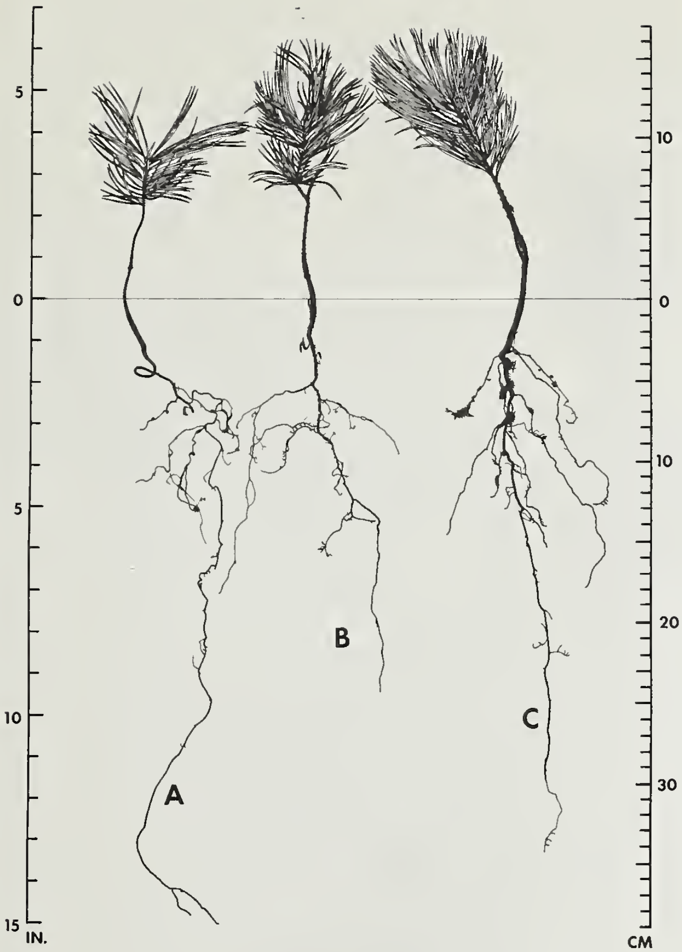


Figure 19.--
White pines after three (A) and four (B and C) growing seasons in the forest.

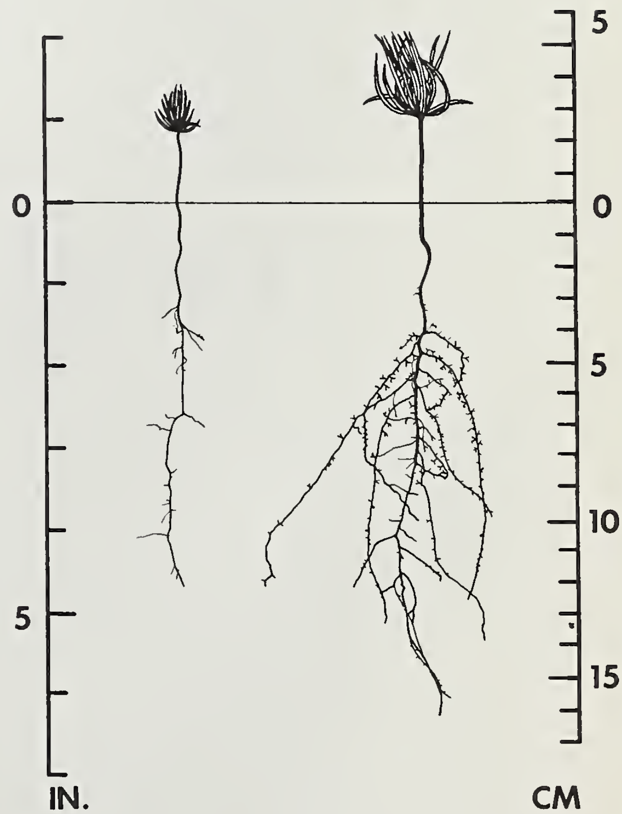


Figure 20.--
Ponderosa pines after one growing season on a clearcutting.

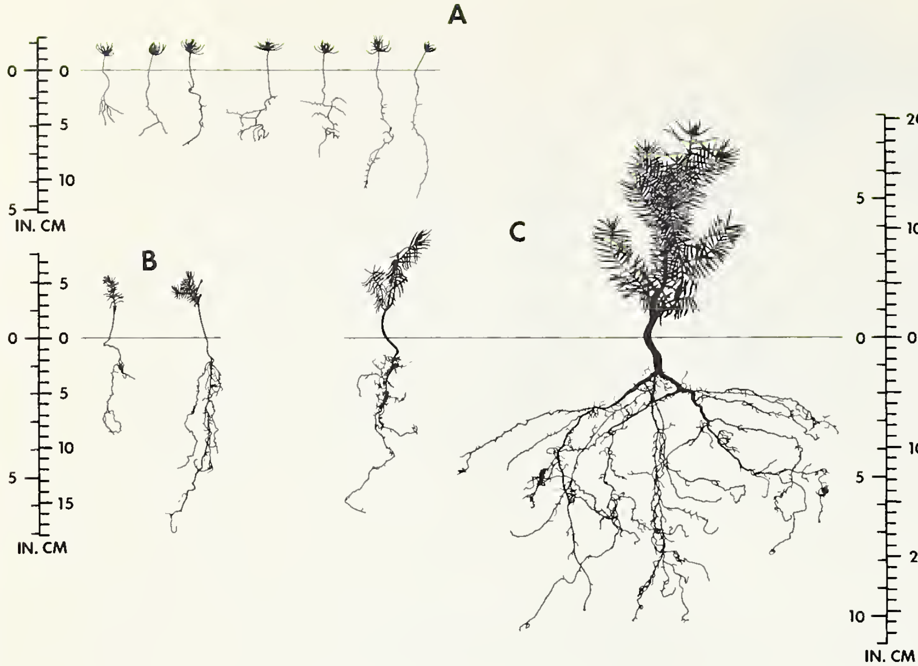


Figure 21.--Douglas-fir.
A. Variation after one growing season within a clearcutting.
B. Largest and smallest third-year seedlings.
C. Largest and smallest fifth-year seedlings.

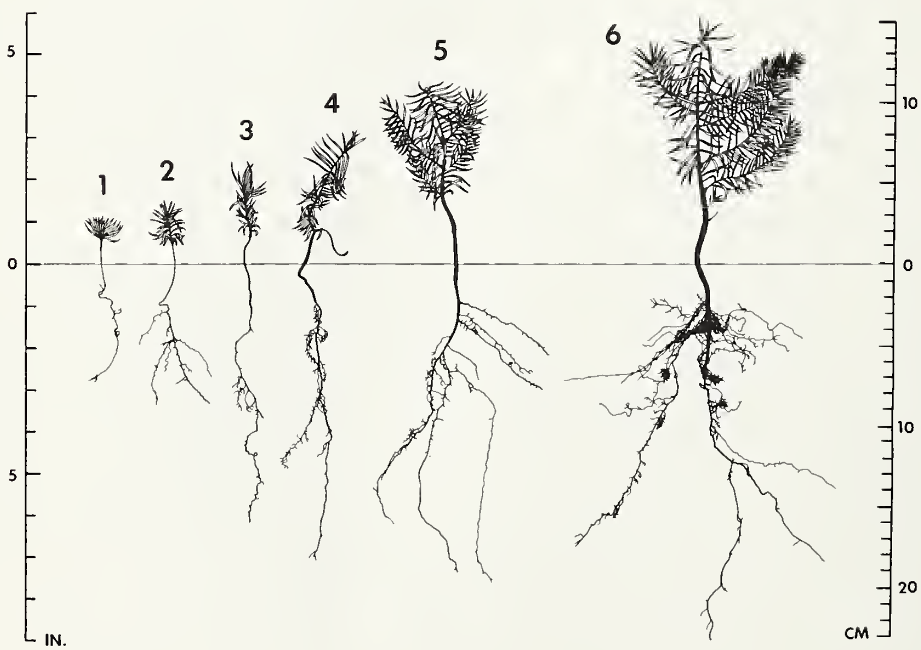


Figure 22.--Representative Douglas-firs after one to six growing seasons. All but no. 1 from a single forested site.

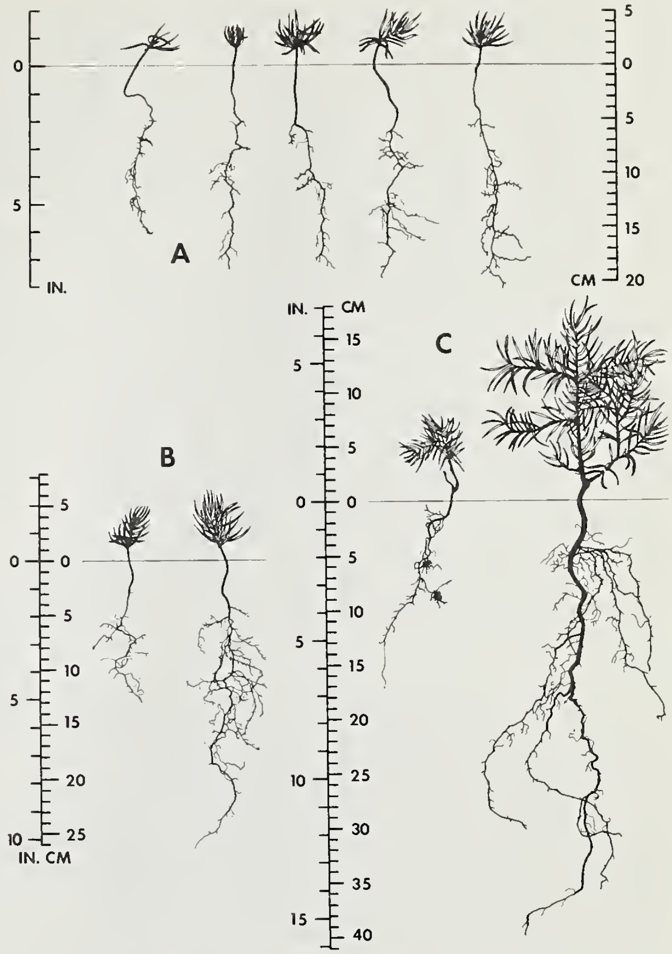


Figure 23.--White fir.
A. Uniformity after one growing season in a clearcutting.
B. Largest and smallest second-year seedlings.
C. Largest and smallest fifth-year seedlings.

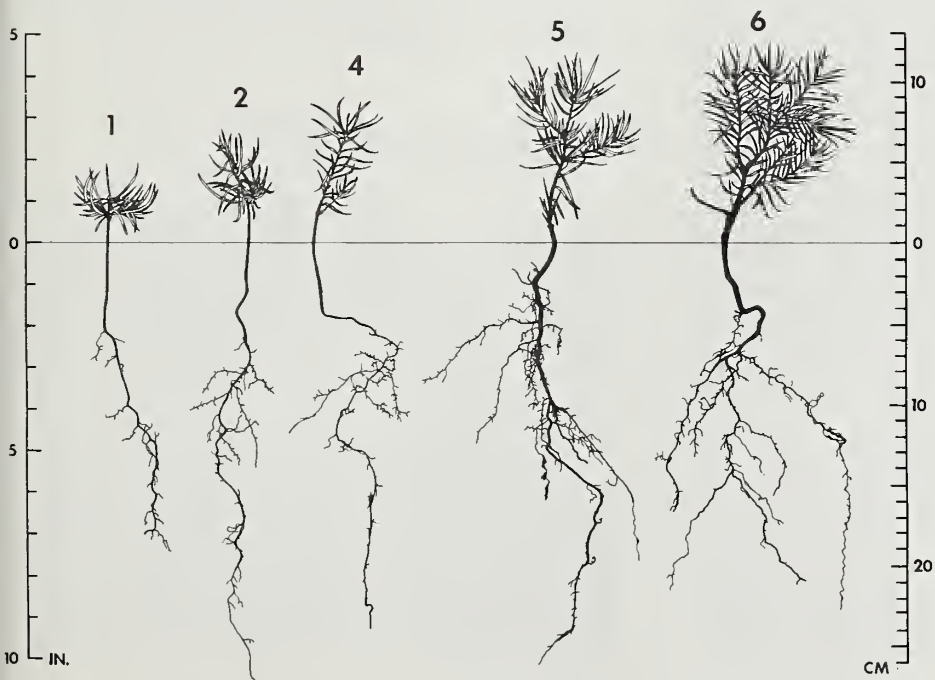


Figure 24.--Representative white firs after one to six growing seasons (no third-year seedling). All but no. 1 from a single forested site.

Seedling root growth continued well into autumn, but by mid-October white tips were few and short; root growth seemed about over. By then the ground had been snow covered twice, and on most mornings the surface was frozen. Development on September 10 and October 15 are compared for corkbark fir (fig. 13) and Engelmann spruce (fig. 16A). During the intervening 5 weeks the roots of Engelmann spruce more than doubled their depth and began to branch. The corkbark firs had germinated perhaps 2 months earlier; their depth did not increase so strikingly during the final 5 weeks, but branching became much better developed.

Within the samples, corkbark fir and Engelmann spruce had the most variable rooting habits. Figure 15 shows corkbark firs from a single site. The seedling on the left had a taproot that appears to be a continuation of the primary root. The one in the center has a taproot developed from a lateral. Although larger than the other two, the seedling on the right, with no taproot, rooted somewhat less deeply.

The most conspicuous variability in Engelmann spruce rooting is in the amount of branching. One seventh-year spruce had branched so profusely that interwoven roots of bedstraw and strawberry could not be separated from spruce roots. Figure 16C shows the most unusual rooting habit found, suggesting a response to highly contrasting root environments or possibly to some root parasite.

The small sample of southwestern white pine is somewhat ambiguous. The first-year seedlings differed considerably in size (fig. 18). The smallest may have germinated late or it may represent inherent seedling variability. From greenhouse observations, white pine seedlings are easily the most variable of the Arizona mixed conifers during their first year, at least in cotyledon length and hypocotyl thickness. Also, the first-year white pines had penetrated about as deeply as the second-year seedlings. That may be a chance result of small sample size, or of different environments. The second-year white pines grew in a rather open virgin stand, and the first-year seedlings in the adjacent clearcutting.

The second-year white pine on the far right of figure 18 appears to have been partly frost-heaved after its first growing season.

Typical fourth-year white pine may well be deeper rooted than those in figure 19; several others about as tall were unusable because their taproots were lost in digging. Even so, those shown were deeper rooted, at their age, than any exhumed seedling of any other species. They also branched more sparsely than any other species examined.

Very few small ponderosa pine seedlings were found in the open, and those in mixed conifer understories are of questionable significance. The largest of the two first-year ponderosa pines (fig. 20) indicates that some root rather deeply and branch abundantly their first growing season. The smaller was probably a late germinant (Larson 1963).

Discussion

Because this was a case history study, it is especially important to consider how representative these growth rates may have been. The clearcutting is extremely gravelly—gravelly enough that part of it has been quarried. And the old roadway has a surface layer to which crushed rock was added. But these soil conditions are not as unusual as they might sound. Gravelly loams are very common throughout the White Mountains, and in the watershed where the principal study sites are found, 56 percent of the area is Sponseller gravelly silt loam.

Perhaps more important in interpreting growth data, the clearcutting studied had considerably less grass than usual. That may account for the unusually large number of tree seedlings, and their good growth.

The abundance of seedlings in the small forest opening probably resulted from disturbance of the forest floor by dragging and burning debris, but in partial cuttings disturbed seedbeds are common.

Comparison of Growth in the Three Degrees of Opening

The small opening, the old roadway, and the clearcutting differed in more than just exposure to sunlight and its effects. Also, degrees of opening were not replicated. But the three sites were similar in important respects, and very near one another on the ground. Thus while no precise or statistical comparisons can be made, a rough comparison is appropriate.

Only Engelmann spruce provided a good sample on all three sites. Even this shade-tolerant species grew much better in full sunlight than in the intermediate illumination of the roadway, and appreciably better in the roadway than in the small opening where seedlings received only skylight and occasional sun flecks (fig. 25).

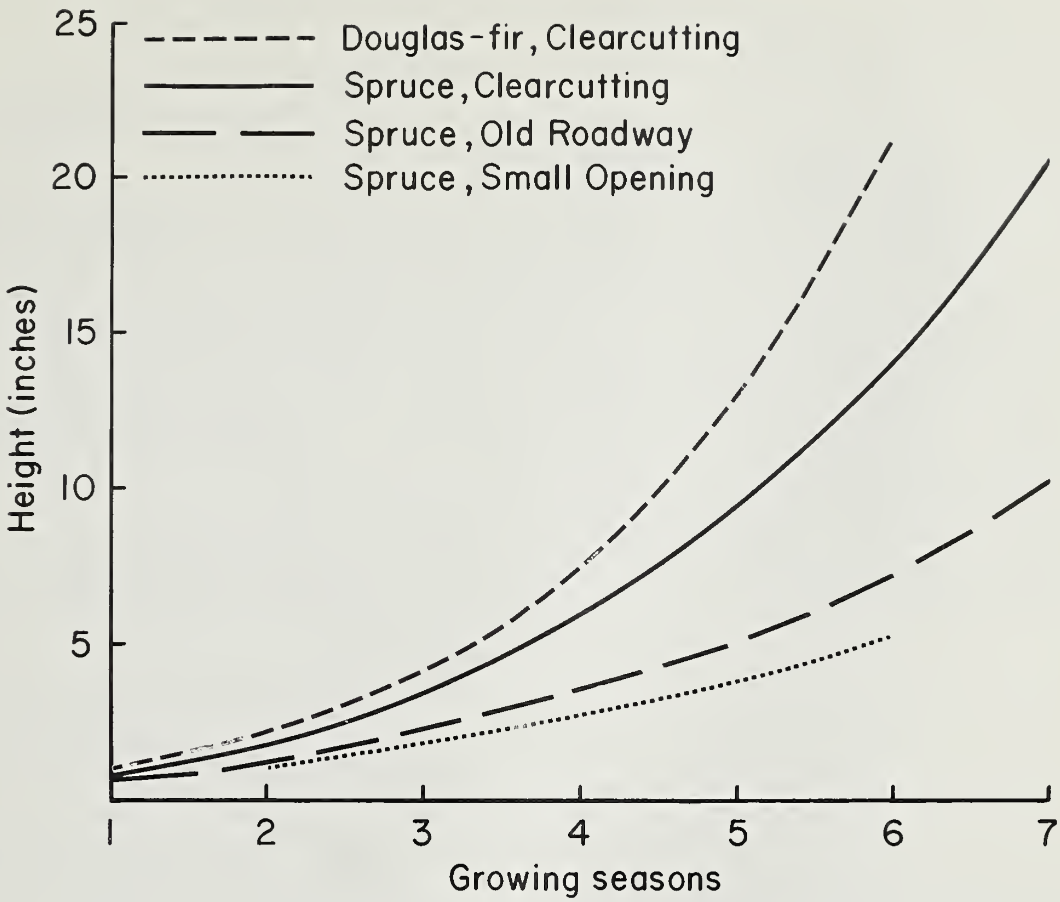


Figure 25.--Growth in three light regimes.

Douglas-fir growth benefited even more from location in the open (fig. 25). Its growth in the old roadway, essentially the same as shown for Engelmann spruce, was much slower than in the clearcutting, while in the small opening Douglas-fir was barely surviving.

A countering consideration to better growth in the open is the seriously greater early mortality of Engelmann spruce seedlings without shade (Ronco 1961, 1967). Some other species may have the same kind of difficulty. The super-abundance of spruce seedlings on the Escudilla Mountain site became established in the protection of a criss-cross of fallen small snags.

Implications for Managers

These findings have implications for forest managers in the White Mountains and elsewhere in the Southwest. The very small first-year root systems of Engelmann spruce and the not much deeper roots of corkbark fir and Douglas-fir make them poor candidates for regeneration from seed where considerable soil drying or frost-heaving are expected. The spring germination habit of corkbark fir and white fir also makes them very susceptible to drying.

The deep first-year rooting of southwestern white pine, as deep as sixth- and seventh-year Engelmann spruce, make it a promising species.

for artificial seeding. Its form is commonly inferior, however, which indicates a need for close spacing and unusual care in seed procurement.

In the selection method, light removals may favor Engelmann spruce and corkbark fir because much of the ground may receive too little light for good survival of white fir and Douglas-fir. Providing a light regime comparable to that in the old roadway should allow Douglas-fir and white fir to survive and develop.

Rapid growth of seedlings in the clearcutting after they reached a height of 4 to 5 inches suggests that planting healthy nursery stock can result in a sapling stand in as few as five to eight growing seasons. Embry [3] found much less soil moisture, however, where grass occupied a mixed conifer clearcutting than where the grass had been removed, except on a north-facing slope. That suggests the seedlings would not grow so fast in the face of vigorous herbaceous competition.

[3] *Embry, Robert S. Soil water availability in an Arizona mixed conifer clearcutting. (In preparation for publication, Rocky Mt. Forest and Range Exp. Sta., Fort Collins, Colo.)*

Literature Cited

Critchfield, W. B., and E. L. Little, Jr.
1966. Geographic distribution of the pines of the world. U. S. Dep. Agr. Misc. Pub. 991, 97 p.

Foiles, M. W.
1961. Effects of thinning seed spots on growth of three conifers in the Inland Empire. J. Forest. 59: 501-503.

Harrington, H. D.
1954. Manual of plants of Colorado. 666 p. Denver, Colo.: Sage Books.

Larson, M. M.
1963. Initial root development of ponderosa pine seedlings as related to germination date and size of seed. Forest Sci. 9: 456-460.

Little, E. L., Jr.
1953. Check list of native and naturalized trees of the United States (including Alaska). U. S. Dep. Agr., Agr. Handb. 41, 472 p.

Ronco, Frank.
1961. Planting in beetle-killed spruce stands. U. S. Dep. Agr., Forest Serv., Rocky Mt. Forest and Range Exp. Sta. Res. Note 60, 6 p., Fort Collins, Colo.

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1967. Lessons from artificial regeneration studies in a cutover beetle-killed spruce stand in western Colorado. U. S. Forest Serv. Res. Note RM-90, 8 p. Rocky Mt. Forest and Range Exp. Sta., Fort Collins, Colo.

Common and Scientific Names of Plants Mentioned[4]

Bedstraw	*Galium* sp. L.[5]
Blue spruce	*Picea pungens* Engelm.
Corkbark fir	*Abies lasiocarpa* var. *arizonica* (Merriam) Lemm.
Engelmann spruce	*Picea engelmannii* Parry
Ponderosa pine	*Pinus ponderosa* Laws.
Quaking aspen	*Populus tremuloides* Michx.
Rocky Mountain Douglas-fir	*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco
Southwestern white pine	*Pinus strobiformis* Engelm.[6]
Strawberry	*Fragaria* sp. L.[5]
White fir	*Abies concolor* (Gord. & Glend.) Lindl.

[4]*Nomenclature follows Little (1953) unless otherwise indicated.*
[5]*Nomenclature follows Harrington (1954).*
[6]*Nomenclature follows Critchfield and Little (1966).*

Jones, John R.
1971. Mixed conifer seedling growth in eastern Arizona. USDA Forest Serv. Res. Pap. RM-77, 19 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado 80521.

Seedling height growth of several species was reconstructed on five case-study areas. Root development of natural seedlings is also shown at different ages. In a small opening receiving no direct sunlight, height growth was very slow. Engelmann spruce and corkbark fir seemed healthy after six growing seasons; white fir and Douglas-fir did not. In an abandoned roadway receiving direct sunlight briefly at midday, growth was moderately faster and all four species seemed healthy. Seedlings grew much faster in a clearcutting, where ponderosa and southwestern white pine also were measured. Growth of Engelmann spruce and corkbark fir understory seedlings released by partial cutting increased markedly. Douglas-fir growth did not. On a burn, growth of Engelmann spruce seemed reduced by intense overstocking. Implications for forest management are discussed.

KEY WORDS: *Pseudotsuga menziesii*, *Picea engelmannii*, *Abies lasiocarpa*, *Abies concolor*, *Pinus ponderosa*, *Pinus strobiformis*, seedlings, roots, overstocking effect.

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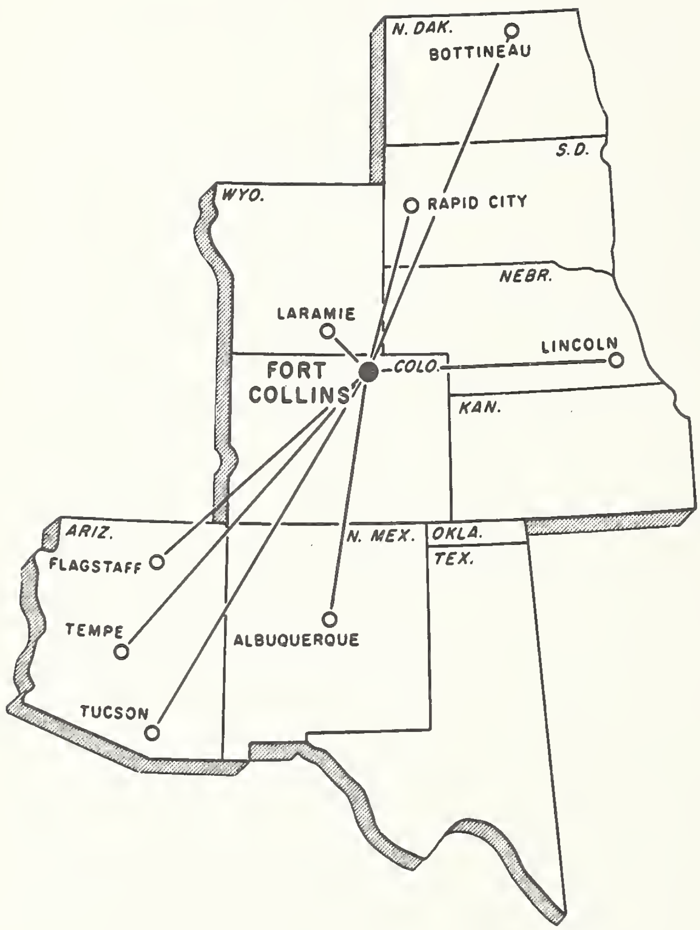
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